

Airport Simulations Using Distributed Computational Resources

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ABSTRACT

The Virtual National Airspace Simulation (VNAS) will improve the safety of Air Transportation. In 2001, using simulation and information management software running over a distributed network of super-computers, researchers at NASA Ames, Glenn, and Langley Research Centers developed a working prototype of a virtual airspace. This VNAS prototype modeled daily operations of the Atlanta airport by integrating measured operational data and simulation data on up to 2,000 flights a day. The concepts and architecture developed by NASA for this prototype are integral to the National Airspace Simulation to support the development of strategies improving aviation safety, identifying precursors to component failure.

INTRODUCTION

Air Transportation studies require an airspace-wide simulation environment that maintains information about baseline operations and estimates the impact of any change before it is introduced. To extend the fidelity of safety simulation to the highest achievable degree and provide seamless, user-transparent access to Air Transportation safety information, a revolutionary technology leap in Intelligent Information Management.

The Virtual National Airspace Simulation is an enabling architecture that is both extensible and scalable to a national level. The VNAS infrastructure consists of a distributed network of supercomputers connected through secure, high-speed ground and satellite links. Smart simulation and intelligent information-integration tools support the management of information and provide the capability to continuously monitor and measure operational performance against expected performance. From this National Airspace-wide simulation environment the FAA, airlines, and other service providers will have a continuously generated performance baseline of the National Airspace. They will be able to extract insightful interpretations of the health and safety of the National

Airspace, making proactive decisions about improvements to aviation safety.

Airspace-wide simulation is a distributed computing problem. A distributed simulation environment is chosen as the preferred approach for several reasons. First, the National Airspace is a large and complex system that is defined by the interaction of many entities. Second, these interactions produce transient effects that can have an impact on safety but are difficult to capture. Third, intelligence is decentralized. A distributed system of data collection, modeling and simulation captures information from numerous sources about these many, complex interactions. Fourth, research teams are located across the country. A whole aircraft simulation comprised of multidisciplinary simulations requires bringing together applications and data that are developed by research teams in different locations. Domain experts plug in models and simulations that will be integral parts of the VNAS, incorporating them into a system-wide model. This article presents a working distributed simulation environment for a VNAS [1].

Because of the complexity of the domain building the VNAS is a gradual process. VNAS prototypes described in this article were developed incrementally over two years. After each step the experience gained was applied to technology evaluation and further concept definition.

VIRTUAL NATIONAL AIRSPACE SIMULATION PROTOTYPE

Building the initial distributed simulation environment included the integration of a supercomputing grid, providing opportunities to identify underlying technological issues such as extensibility and scalability. Early on, security and network communications were addressed. Data, models and simulations required compartmentalized views, and data and applications were distributed across the United States. Also, integration of monitoring and simulation data and

applications were addressed. Object models of components of the airport/airspace became numerous and complex, made up of multidisciplinary simulators.

The prototype VNAS' Milestone Requirements were twofold:

- Develop a batch capability running on a distributed network of super-computers located at Ames, Glenn, and Langley Research Centers. Perform nightly batch runs of engine, landing-gear, and wing simulations.
- Establish infra-structure for processing real-time input.

The initial prototype of a National Airspace Simulation runs on NASA computers located across the United States. Operational data from up to 2,000 daily flights were batch processed by the aircraft component simulators. The result is a virtual model of aircraft at Atlanta's Hartsfield International Airport. The objectives were fourfold: 1) identify and understand underlying technological issues, 2) understand management of a complex distributed simulation process and integration of measured operational data and simulation data, 3) design, implement, and test simulation middleware that will support data integration and interoperability with distributed simulation systems, and 4) evaluate grid-services such as single-point authentication and authorization, remote job submission, and secure file-transfer.

The VNAS prototype uses measured operational data about individual aircraft when it exists. Where aircraft operations are not measured simulation data is used to complete aircraft models. At Hartsfield Airport large amounts of operational data are collected every day. Radar, airline schedules, FAA flight-plans, and weather data are examples of the data-collection programs that provide monitoring data to the VNAS prototype. In the air, FAA Terminal Radar Approach Control (TRACON) tracks every takeoff, approach and landing. Local weather conditions are constantly monitored and recorded by the National Weather Service. Subassembly simulators are driven by this data and produce simulation parameters that depict states and conditions within key aircraft subassemblies.

Measurement and simulation data are inserted into flight equations and combined with graphic imaging software. The result is a computer simulation that provides a composite view of the aircraft that reflects multiple disciplines. Representative operations data and parameters from engine simulations are depicted in Figure 1.

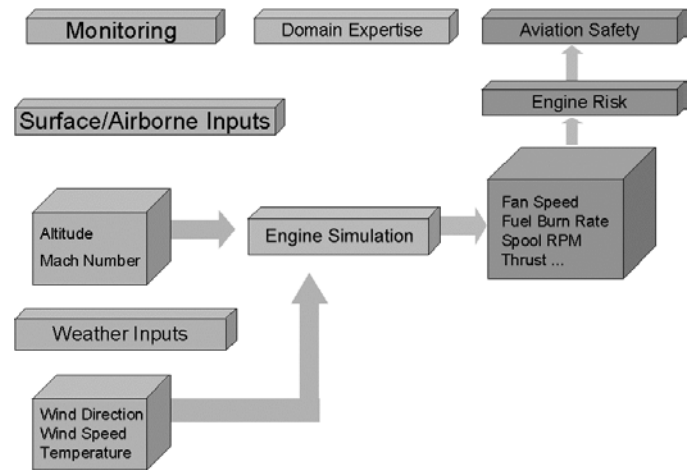


Figure 1. Engine simulator driven by measured operational data

The VNAS prototype is comprised of the following: 1) Intelligent Information Management Concepts, Architecture, and Technologies [2], 2) distributed, large-scale computational resources, and 3) simulation and application/data integration components. Together they produce a model of airport operations. New concepts and tools called Intelligent Information Management support the integration of both applications and data.

INTELLIGENT INFORMATION MANAGEMENT CONCEPTS, ARCHITECTURE, AND TECHNOLOGIES
Intelligent Information Management involves locating, organizing, and adding value and access to data throughout its life in an enterprise. For the prototype VNAS, it consists of three major parts: 1) an advanced communication network, 2) the Intelligent Information Management Architecture, and 3) Intelligent Information Management Services. Network communication is provided by NASA Research and Education Network [3]. The Intelligent Information Management Architecture, which is adaptable to common needs of DOD and NASA's other Enterprises, supports the management of complex operational environments. It is represented in Figure 2.

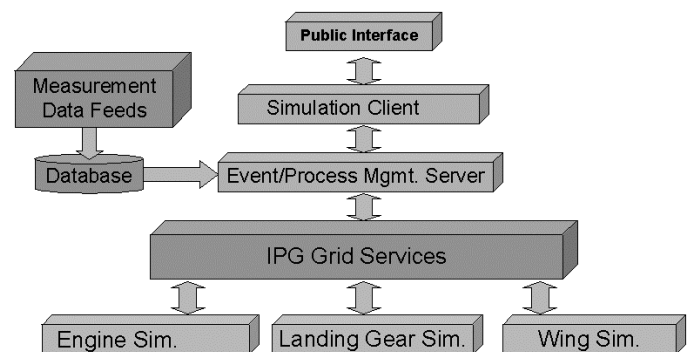


Figure 2. Architecture for VNAS Prototype

Because the secure, adaptable bus-like architecture accommodates a wide range of network-communication and processing needs, it is the key enabling technology that will allow full use of Air Transportation safety information. Intelligent Information Management's suite of smart services collaborate with each other and communicate with users via this network.

These concepts and technologies, developed and implemented in the prototype, are represented by a suite of management and integration services that are connected through a distributed network of supercomputers via secure, high-speed links. These services control the execution of distributed simulations and integration of operational and simulation data.

DISTRIBUTED COMPUTATIONAL RESOURCES

Large-scale computational resources are required by a VNAS. They are needed to support the integration of hundreds of aircraft performance models. Computational capabilities that will be required for National Airspace-wide simulation are suggested by the current and future requirements listed in Table 1.

Current Capability	Capability Needed By 2010	Capability Needed by 2020
100 million floating-point instructions (MF), 100 megabytes per airport simulation	10 billion floating point instructions (GF), 20 gigabytes per simulation	20 GF, 1 terabyte per simulation
Navier-Stokes, airframe only, cruise --> 10 hours	Multi-discipline simulation, airframe only, landing/takeoff --> 1 hour	Multi-discipline simulation, airframe + propulsion, landing/takeoff --> 1 minute

Table 1. Current and Future Need for Computational Resources [4]

NASA's Information Power Grid, a high-performance grid made up of a distributed network of supercomputers running over advanced networks, is employed in the VNAS prototype [5].

SIMULATION AND INTEGRATION COMPONENTS

The four major parts of the initial simulation prototype and the NASA centers of expertise responsible for aircraft subassembly simulation and information integration are listed in Table 2.

Expertise/VNAS Component	Function/Center of Expertise
Aero-propulsion: Numerical Propulsion Simulation System (NPSS) [6]	Engine simulation (NASA Glenn Research Center)
Airframe Systems: Boeing 737 Simulation [7]	Landing-gear simulation (NASA Langley Research Center)
Aerodynamics: Boeing 747 Wing Simulation [8]	Aerodynamic simulation (NASA Ames Research Center)
Intelligent Information Management	Simulation control and data distribution, retrieval, and integration (NASA Ames Research Center)

Table 2. Expertise for aircraft subassembly simulations and integration

The focus of the initial prototype is on basic simulation. Engine simulation is provided by the Numerical Propulsion Simulation System (NPSS). NASA and engine manufacturers worked together on NPSS. It provides shaft speed and inlet/outlet temperatures and pressures at each stage. There is a high level of confidence in NPSS and engine manufacturers are using it in designing new engines. Landing gear simulation is provided by a 737 simulator. NASA and Boeing worked together on this simulator which provides forces and moments for landing-gear. It has been validated and used for a number of years.

The wing simulation is a simple wing model which produces aerodynamic coefficients, such as lift and drag, and forces and moments. Graphs of lift-coefficients are illustrated in Figure 1. The solid line represents a baseline curve for arrivals at Hartsfield International Airport. The broken lines represent lift coefficients for two arrivals. The wing simulator has not been validated.

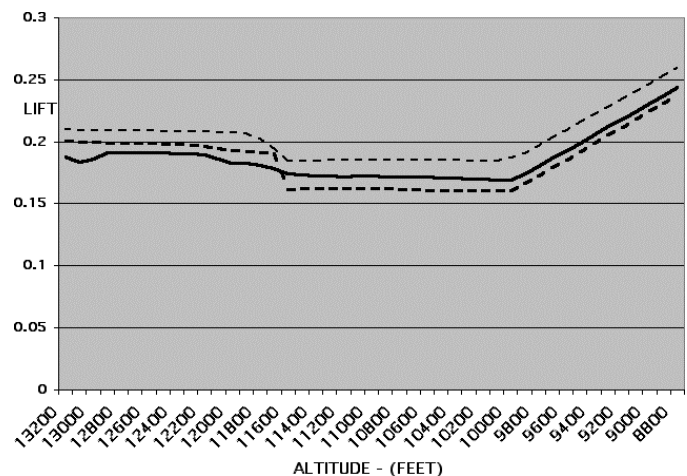


Figure 1. Arrival Lift coefficients v. alt. – baseline (solid) and two flights

A central executive is needed to regulate the simulators and manage the large amount of data that is generated.

Intelligent Information Management services run on a computer at an Intelligent Information Node. They control automated batch processing of an entire day's flights. This central site also manages the interactive requests for simulations by scheduling and controlling the execution of engine, landing-gear, and wing simulations.

The Intelligent Information Node manages these requests by disseminating operational data and invoking engine, landing gear and wing simulations on remote computers. From a simulation-integration point of view every simulation is similar. First, the Intelligent Information Node sends operational data (i.e., radar-tracks and surface data) as input to each simulation site. The input data is processed by simulation software running at the remote site. For each flight the simulator produces simulation data that reflects the state and performance of a particular aircraft subassembly. When simulations from multidisciplinary perspectives have finished, services manage the retrieval and integration of

simulation and monitoring data. This creates a virtual model of each aircraft.

The simulation parameters generated by subassembly simulations and integrated by services are stored for analysis. Monitoring and simulation data can be viewed via a visualization tool, trended and analyzed for risk exposure. For example, weather data, flight-plans, radar-tracks and simulation parameters are linked together into a consolidated view that can be analyzed for structural stress or other risk exposure measurements.

APPLICATIONS

As VNAS prototypes evolve they will support improvements in aircraft design and reduction in operational costs. Airport simulations using distributed resources can be applied in three areas. First, multidisciplinary airport simulations can be inserted at the front end of the engineering design process. Simulations of interdependent components can provide airframe manufacturers with risk exposure measurements for new designs or modification of existing ones. This early understanding of a new design or change can be fed back into the process, reducing overall design time. Second, whole aircraft simulations can be used by airlines to assess the impact of current or proposed policies and procedures on operations and maintenance. Insight from subassembly simulations of engines can lead to condition based maintenance and more optimal scheduling of repairs. Third, whole airport simulations including noise and emissions as well as risk exposure measurements provide a more complete picture of operational changes before they are made. Multiple airport simulations across a range of conditions can provide insight into possible safety and cost issues. This knowledge can then be used in making decisions on airport policy or procedural changes.

FUTURE EXTENSIONS

The following extensions are recommended: 1) validate subassembly simulations and continue to refine them, 2) extend models and integration to include safety and risk exposure measurement, 3) expand data sources and scope of monitoring data for greater coverage of the United States, 4) incorporate smart middleware and technologies such as XML-converters and interpolation techniques to integrate data from heterogeneous databases, 5) test technologies that enable two-way information flows such as capturing and feeding back safety information from multi-discipline flight simulations to pilots, 6) investigate proposed standards and technology that support Aerospace-specific Intelligent Information Management, 7) continue collaboration with groups who are working to create large-scale computational grids.

CONCLUSION

For the National Airspace to increase throughput of Air Transportation requires a nation-wide simulation

environment that has the highest achievable degree of fidelity. The solution described in this paper, Intelligent Information Management, provides infrastructure to support a Virtual National Airspace Simulation. New concepts can then be inserted into real-time National Airspace-wide simulations. Analyses of performance can be a basis for evaluating proposed methods and technologies and making proactive decisions about improvements to aviation safety.

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